Exotic and precise: the magnetic dipole moment of 57Cu by in-source laser spectroscopy.

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May 27, 2009

Outline

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1. In-gas-cell resonant ionisation laser spectroscopy
   - Laser spectroscopy
   - The LISOL gas catcher
2. The dipole moment of the copper isotopes
3. Conclusion

From atomic to nuclear physics

A matter of scale and overlap

Atomic Physics

+ Nanoscale: 10^{-9} m
+ Transitions: around visible
+ Point-like nucleus

Nuclear Physics

- Femtoscale: 10^{-15} m
- Transitions: γ radiation
- Complex nuclear structure

- To first order, atomic physics is purely determined by the number of protons (Z) with no extra effects from the nucleus.
- However the nucleus can perturbe the atomic system. Measuring small perturbations of the atomic structure can reveal nuclear information.

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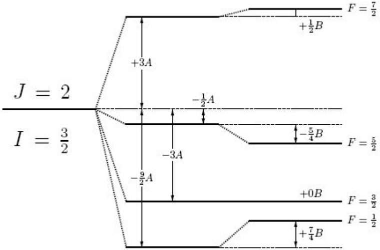
Hyperfine Structure

$$A = \frac{\mu |H_0|}{IJ}, \qquad \Delta E = \frac{A}{2} \cdot K + \frac{B}{2} \cdot \frac{3K(K+1) - 2I(I+1)2J(J+1)}{2I(2I-1)2J(2J-1)},$$

$$B = \frac{eQ}{4} \cdot \frac{\partial^2 V}{\partial z^2}. \qquad \text{where } K = \Big(F(F+1) - I(I+1) - J(J+1)\Big).$$

HFS

High order multipoles in the expansion of the Coulomb interaction between the nucleus and the electron perturbate the energy levels.



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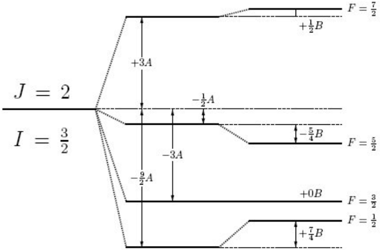

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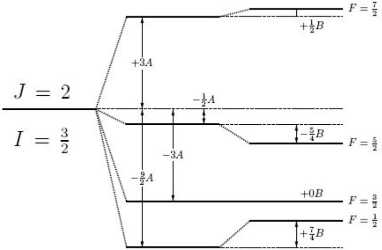
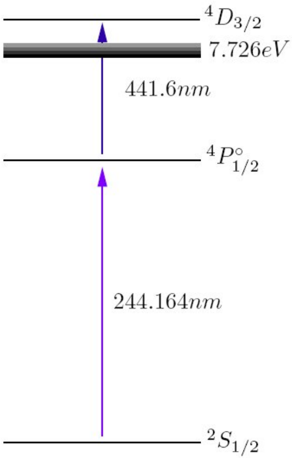


Resonant laser ionisation

- The lasers are tuned to resonantly excite the electronic population accross the atomic levels until the electron is close to or beyond the ionisation potential.
- The efficiency ranges from 1% to 40%.
- Only the copper atoms can be excited by this particular scheme.



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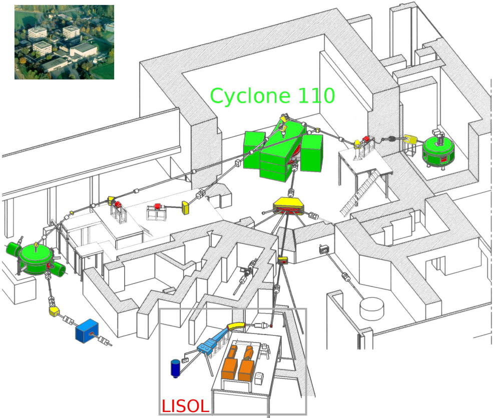
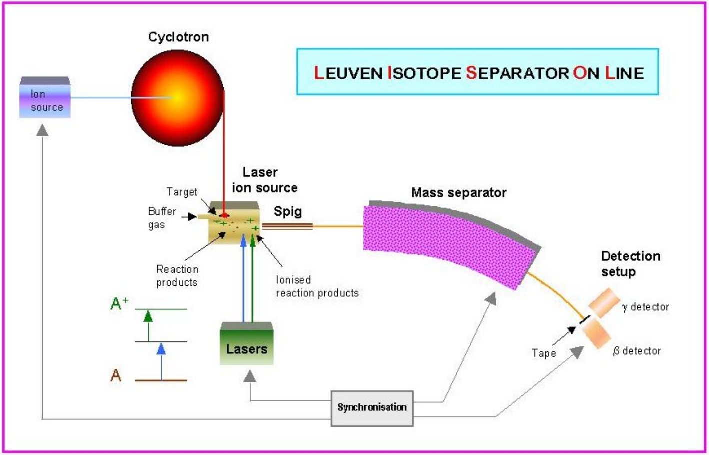
In-gas-cell laser spectroscopy
CRC facilities

CRC = Centre de Recherche du Cyclotron (Cyclotron Recherche Center), Louvain-La-Neuve (Belgium)



In-gas-cell laser spectroscopy
CRC LISOL facility

LISOL = Leuven Isotope Separator On-Line



In-gas-cell laser spectroscopy
CRC LISOL LIS

LIS = Laser Ion Source

In-gas-cell laser spectroscopy

Line shape

The resonance profile is a very mixed Voigt profile with an almost equivalent contribution of both the Gaussian and the Lorentzian part.

Gaussian Δ

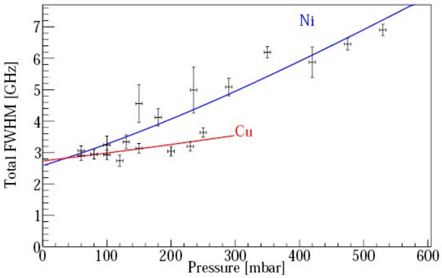
- $\approx$ Laser line shape;
- Doppler broadening ($T \approx 300$ K).

Lorentzian Γ

- Laser power broadening;
- Pressure broadening (linear in pressure)

$$\text{Total width} = 0.5346 \cdot \Gamma + \sqrt{0.2166 \cdot \Gamma^2 + \Delta^2}$$

In-gas-cell laser spectroscopy
Line shape



Typical FWHM for Collinear Laser Spectroscopy ranges from 1 to 100 MHz.

In-gas-cell laser spectroscopy
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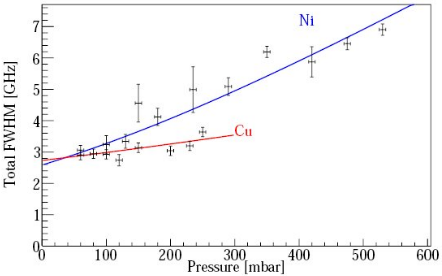

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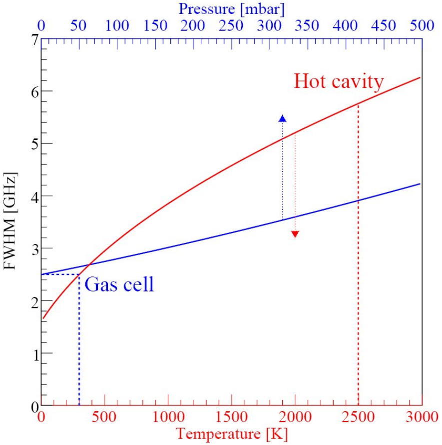
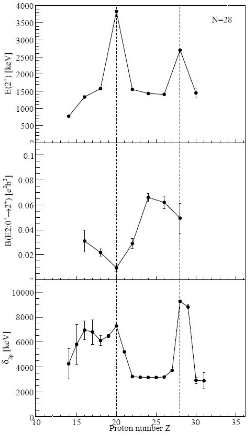
In-gas-cell laser spectroscopy

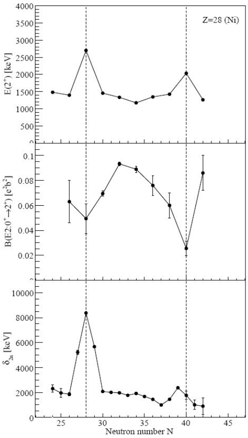
vs. in-hot-cavity laser spectrosopy



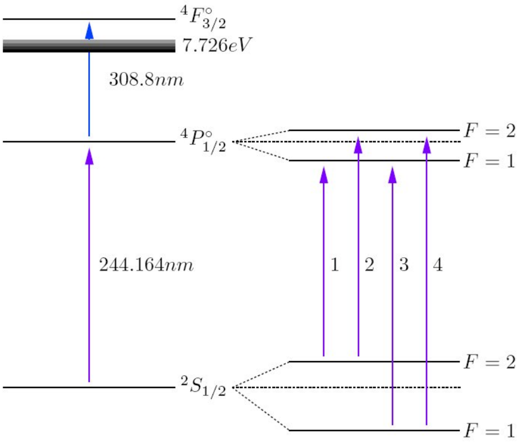
Persistance of magicity?
$Z = N = 28$



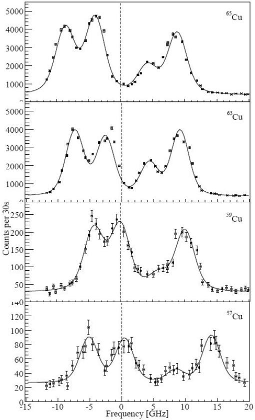
- + High $E(2^+)$
- - High $B(E2)$
- + Sudden change in S_{2p} and S_{2n}



In-gas cell laser spectroscopy of Cu



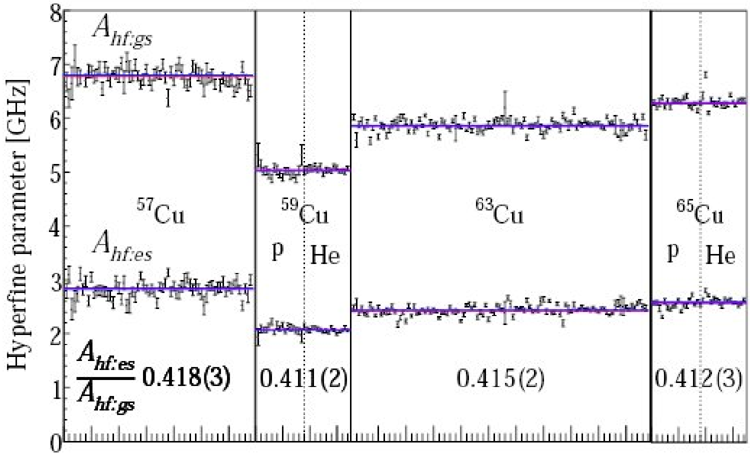
In-gas cell laser spectroscopy of Cu
Spectra



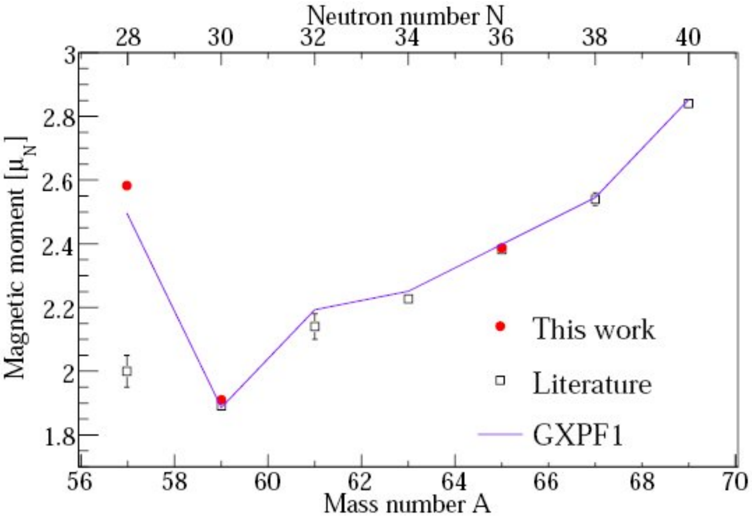
- FWHM = 3 GHz
- Relative heights are very much influenced by the gas cell conditions and cannot be relied on for spin determination
- The very large HFS of Cu allows for precise determination of the magnetic dipole moment

In-gas cell laser spectroscopy of Cu

Stability



Magnetic moments of Cu



Conclusion

- In-gas-cell laser spectroscopy is a technique that can provide precise magnetic dipole moments for elements with high hyperfine parameters or high moments;
- The magnetic moment of ^{57}Cu is now well understood;
- Magicity at $N = Z = 28$ not absolute;
- Isotope shifts can be measured as well but the changes in the mean-square charge radii can only be extracted for heavy elements.

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Future

. . . of in-gas-cell laser spectroscopy

After successfully demonstrating the power of the technique with the Cu isotopes, the propositions are to

- study the Ag, In, Sn isotopes towards $N = 50$;
- study the Au isotopes around mid-shell $N = 104$;
- study eventually the Rg isotopes, super-heavy elements following directly Cu, Ag and Au on the periodic table;
- install such ion sources in the new facilities (PALIS@RIKEN, S^3@GANIL, FRIBF@NSCL).

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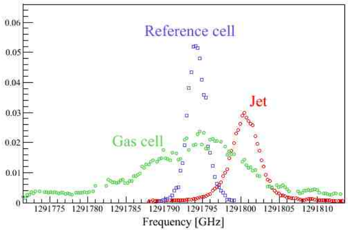
Future

. . . of resonant ionisation spectroscopy

LIST = Laser Ion Source Trap

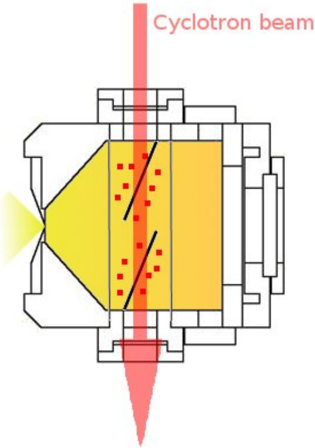


By performing the ionisation outside the gas cell directly in the ion guide following the gas cacher, the pressure broadening can be greatly reduced and the resolution improved.

The end

Thanks…

Laser ionisation
in a gas catcher



Laser ion source

- The atoms are produced on-line or evaporated from a filament,
- The ions thermalise in the buffer gas at room temperature,
- The lasers are sent through the gas cell to ionise the atoms of interest,
- The ions are then extracted from the gas cell in the sonic jet.

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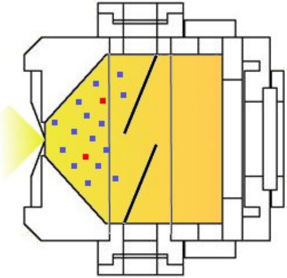

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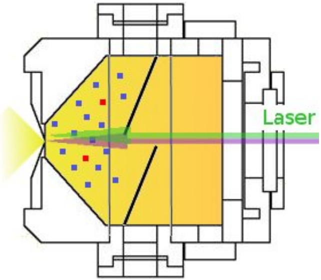

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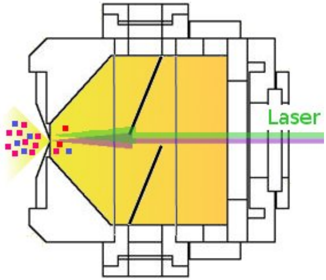

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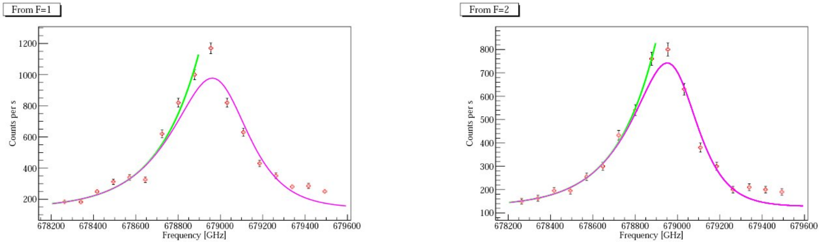
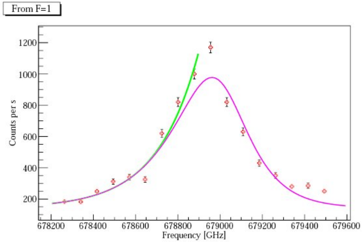
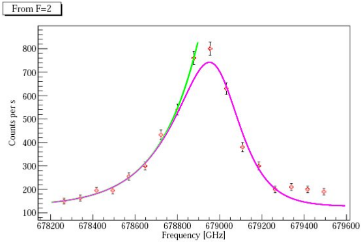
In-gas-cell laser spectroscopy
Second step

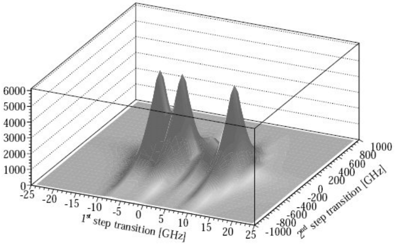


The second transition is so broad ($\approx$ 500 GHz) that it has no effect on the first transition.

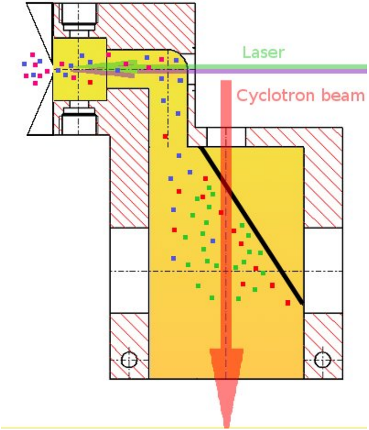
In-gas-cell laser spectroscopy
Second step





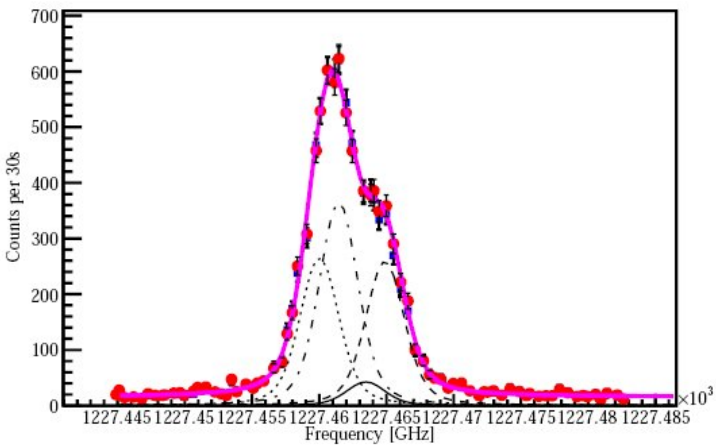


Shadow gas cell



Limits of the technique

^{58}Cu



Isotope shift

$$\delta\nu^{AA'} = \frac{A' - A}{A \cdot A'} \cdot (m_e\nu + K_{SMS}) + F \cdot \delta\langle r^2\rangle^{AA'}.$$

Mass shift

$$\delta\nu_{MS}^{AA'} = \frac{A' - A}{A \cdot A'} \cdot (m_e\nu + K_{SMS}).$$

The change in the reduced mass of the nucleus-electron system affects the energy levels, hence affecting the transition as well.

Field shift

$$\delta\nu_{FS}^{AA'} = F \cdot \delta\langle r^2\rangle^{AA'}.$$

The change in the mean-square charge radius of the nucleus affects the energy levels (s- and $p_{1/2}$-electrons only).

Changes in the mean-square charge radii ?

King plot